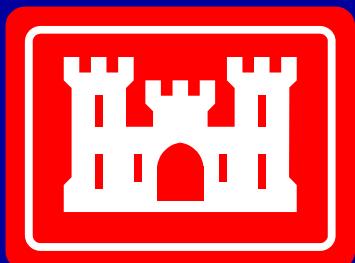


# BOREHOLE GEOPHYSICS FOR INVESTIGATIONS OF GROUND-WATER CONTAMINATION IN FRACTURED BEDROCK

John Williams  
U. S. Geological Survey  
Troy, New York



University of  
**Waterloo**

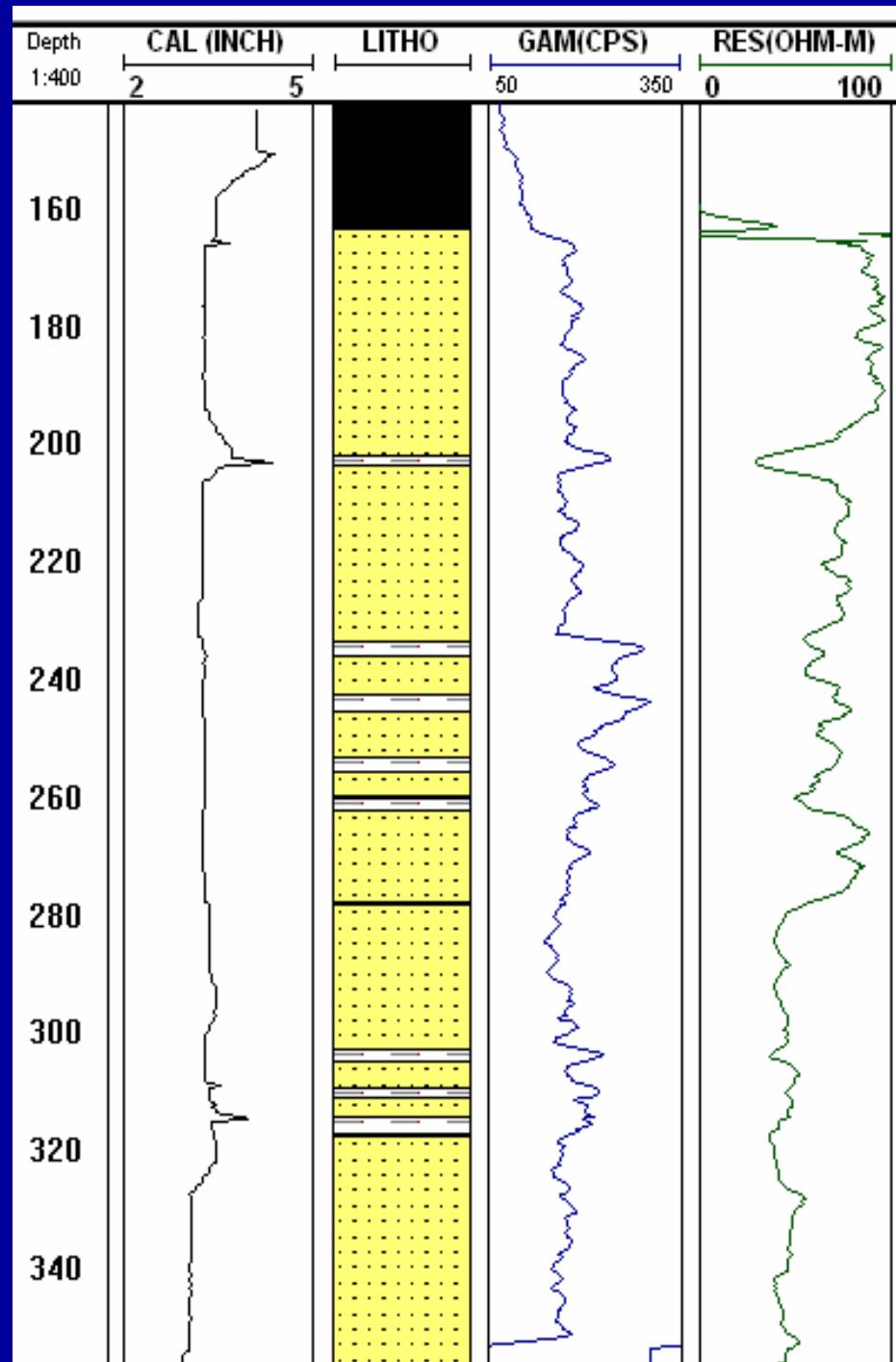


# BOREHOLE-GEOPHYSICAL METHODS

- Geologic framework
  - Lithologic delineation and stratigraphic correlation
  - Bedding, fabric, and fracture orientation
- Hydraulic properties of flow zones
  - Estimate transmissivity and hydraulic head
  - Determine hydraulic connectivity
  - Design of discrete-zone water-level monitoring
- Contamination
  - Preliminary assessment
  - Evaluate cross-connection issues of open holes
  - Sampling of open holes
  - Design of discrete-zone water-quality monitoring

# BOREHOLE-GEOPHYSICAL METHODS

- Gamma and resistivity
- Borehole-wall image
  - Acoustic televiewer
  - Optical televiewer
- Fluid property
  - Fluid resistivity or conductivity
  - Temperature
  - Point sampler for VOC sample analysis
- Flow
  - Heat-pulse flowmeter (stationary)
  - EM flowmeter (stationary and trolling)



**Rocket testing facility in southern California with an identified DNAPL source**

**Cretaceous sandstone and mudstone sequence**

**Beds dipping to the northwest**

**Deep corehole in source zone**

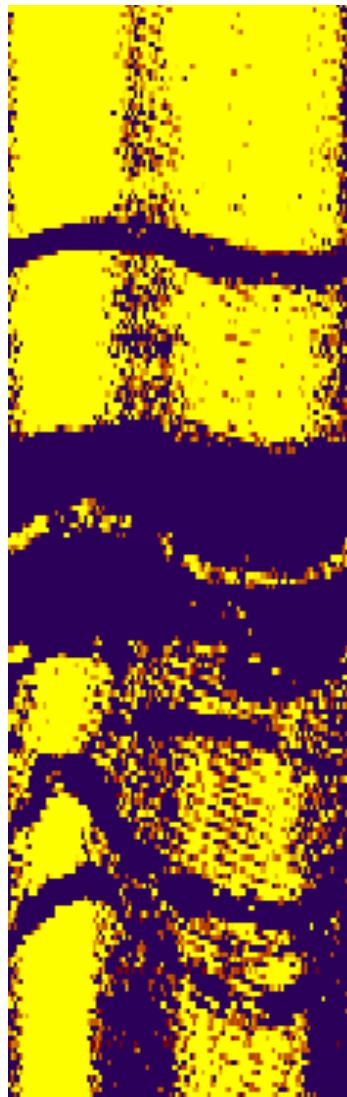
Sterling(1999), Williams and others (2000), and Sterling and others (in prep)

# Bedding and Fracture Characterization

N E S W N      N E S W N

DEPTH BELOW TOP OF CASING, IN METERS

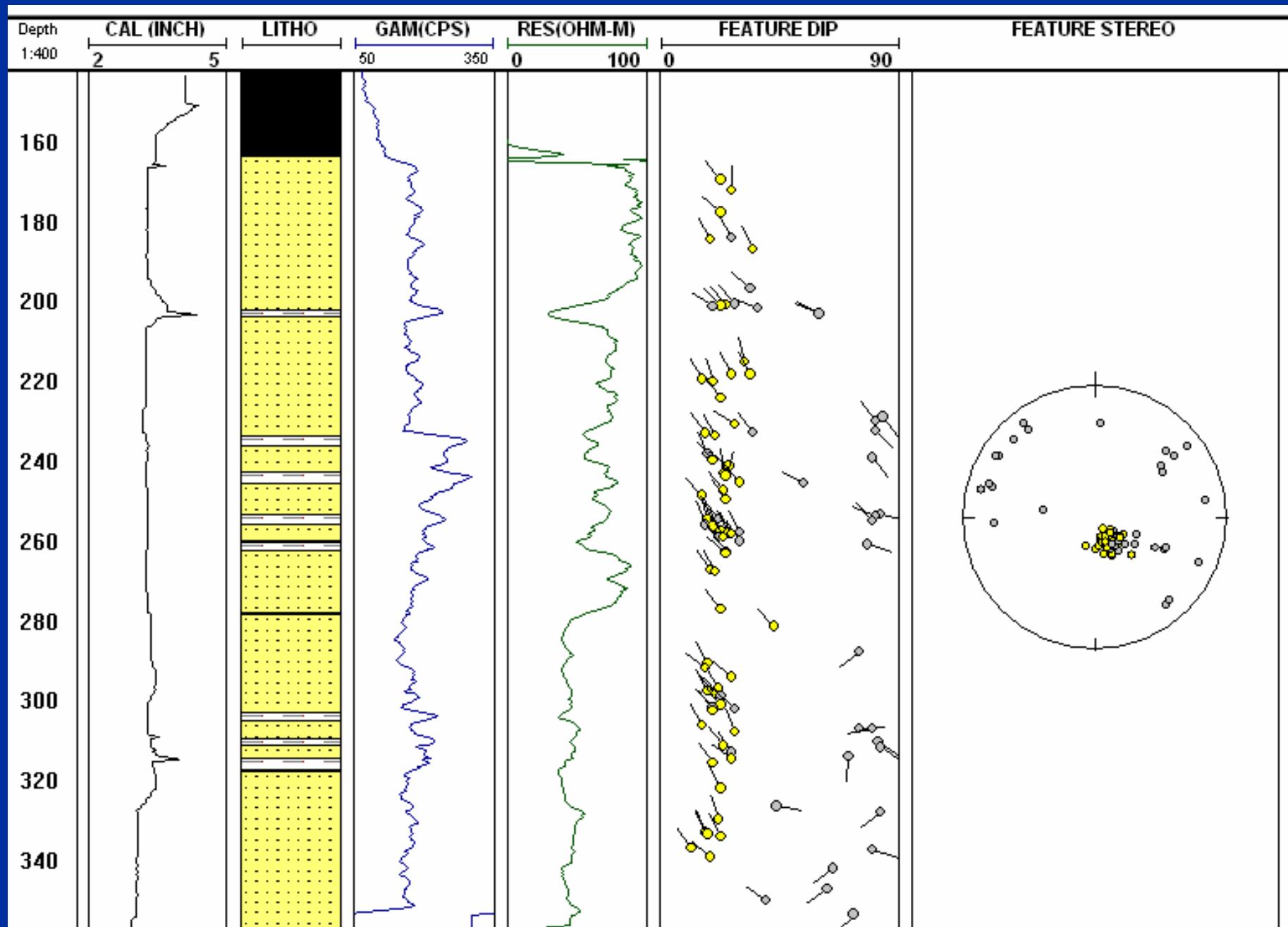
61.5  
62.0



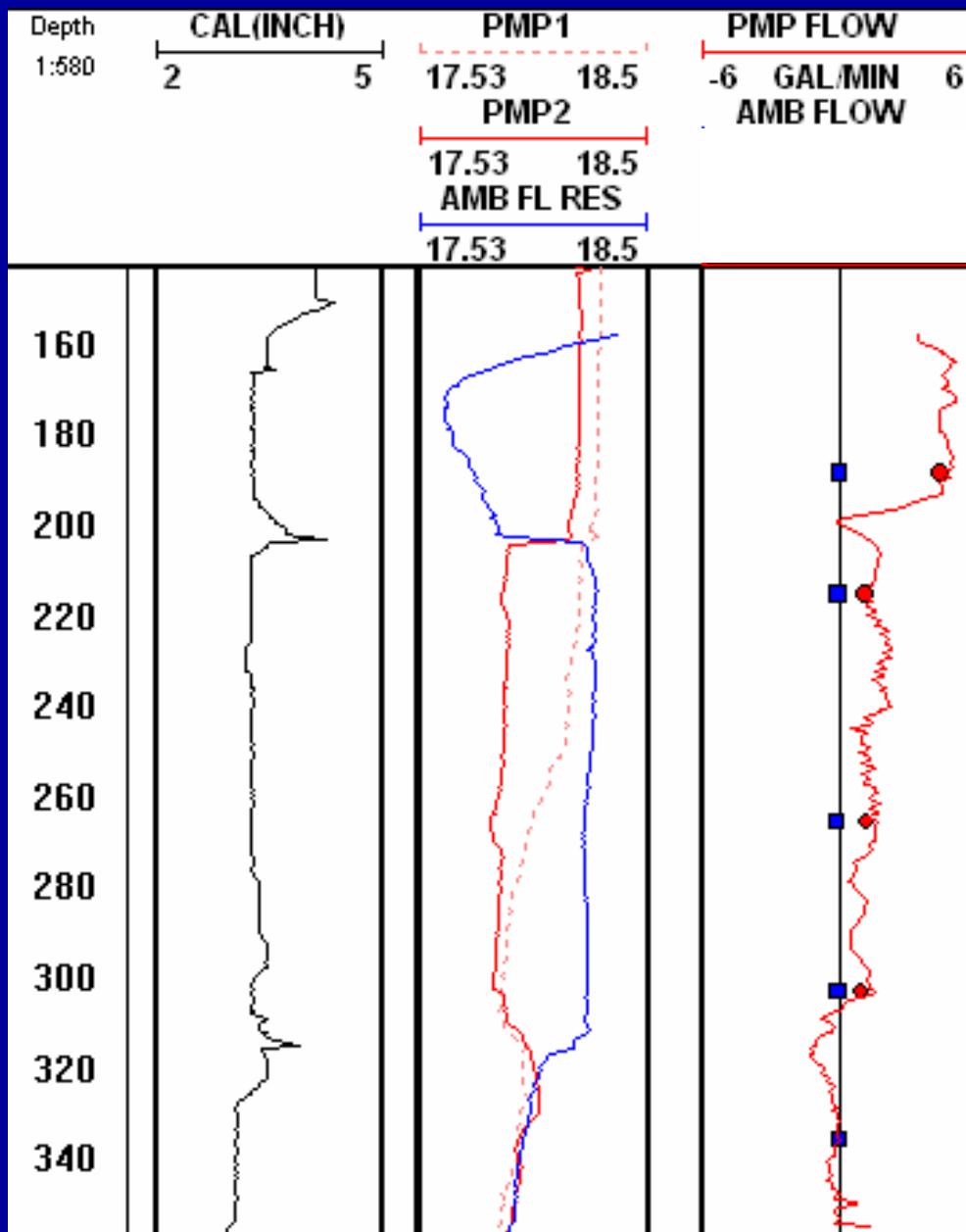
Acoustic



Optical



# FLUID AND FLOW LOGGING UNDER AMBIENT AND PUMPED CONDITIONS



Flow zones at  
201 and 312 feet

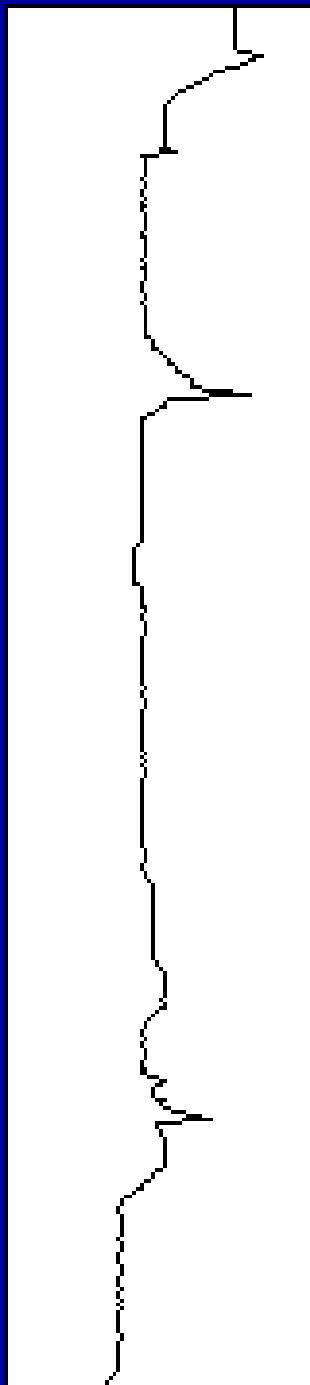
Downward  
ambient flow

## 201 FOOT ZONE

**Bedding  
fractures**



**Intermediate  
angle fractures**



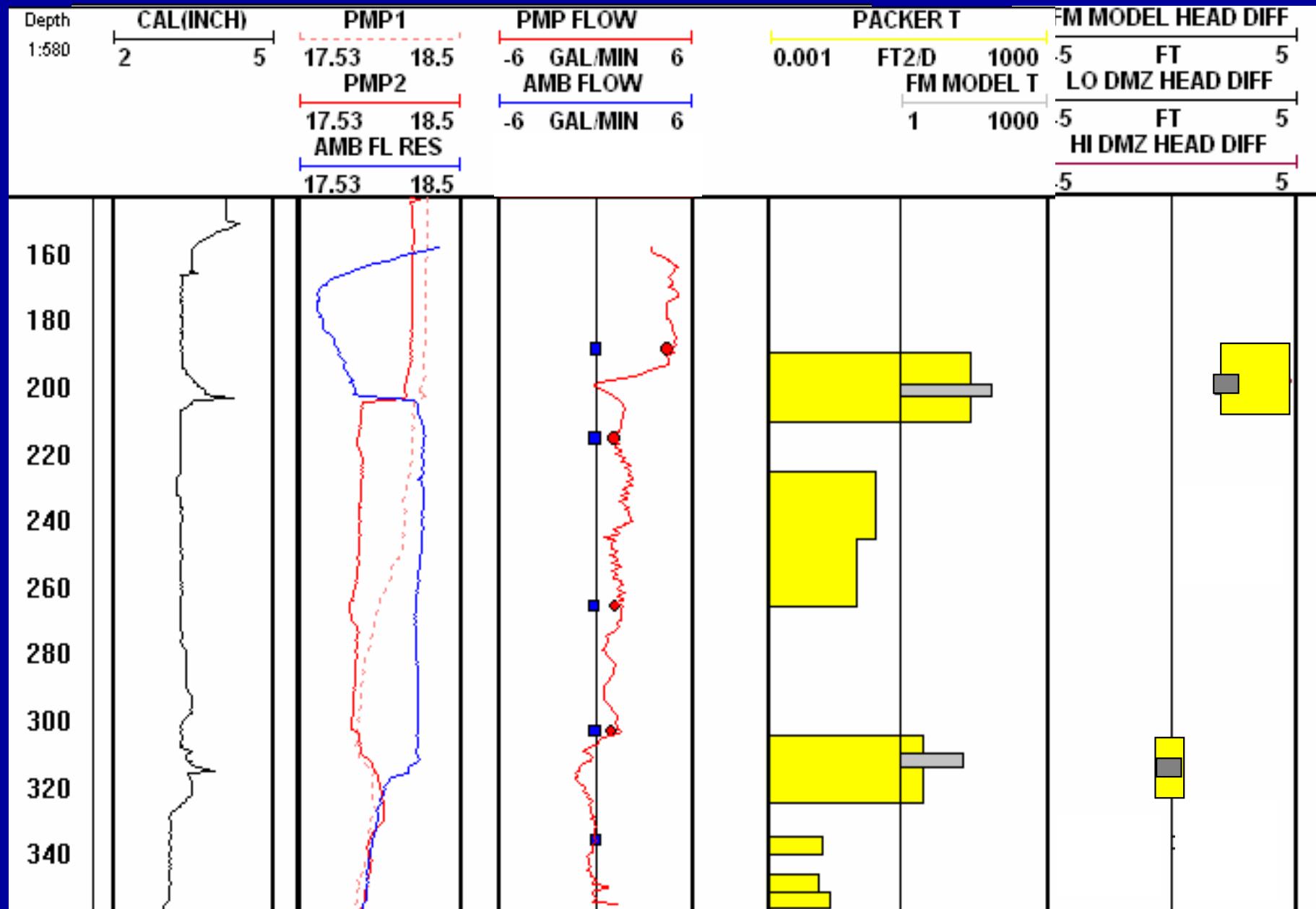
**High angle  
fractures**

**Bedding fracture**

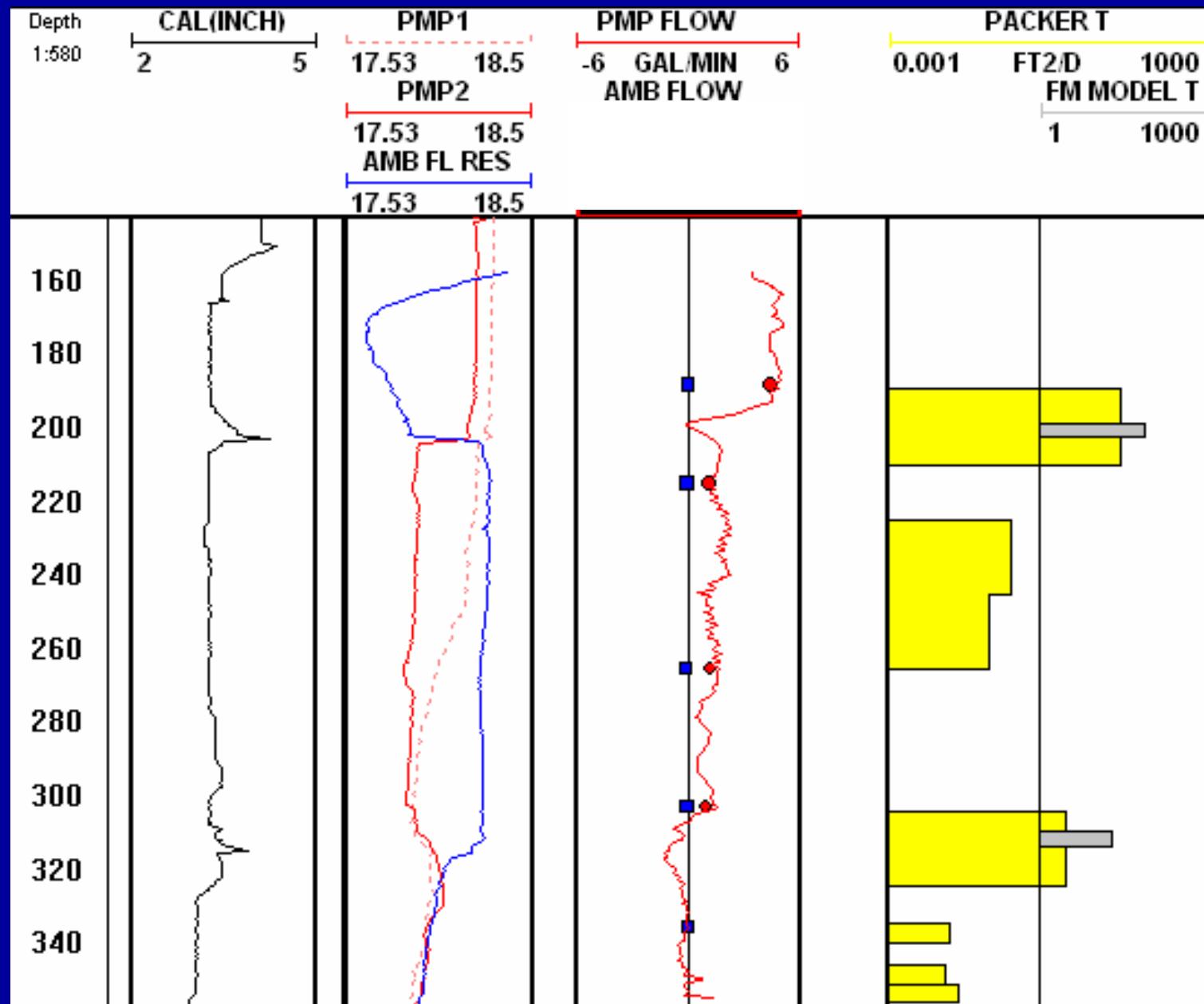
## 312 FOOT ZONE

# TRANSMISSIVITY AND HEAD OF FLOW ZONES

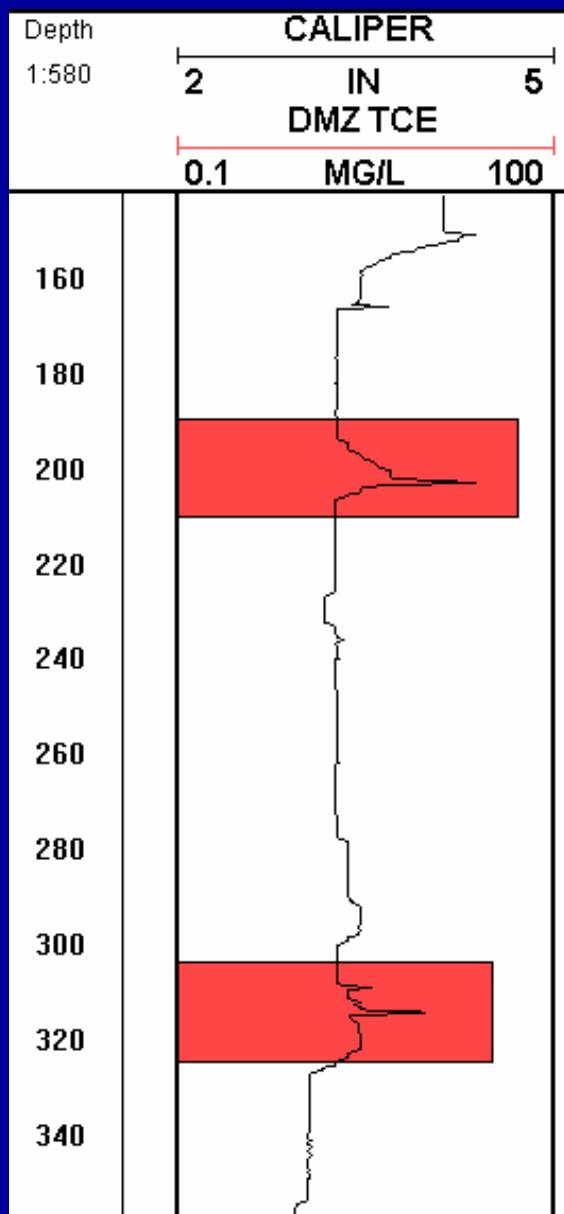
## Straddle Packer and Flowmeter



# FLOWMETER DETECTS THE MOST TRANSMISSIVE FLOW ZONES



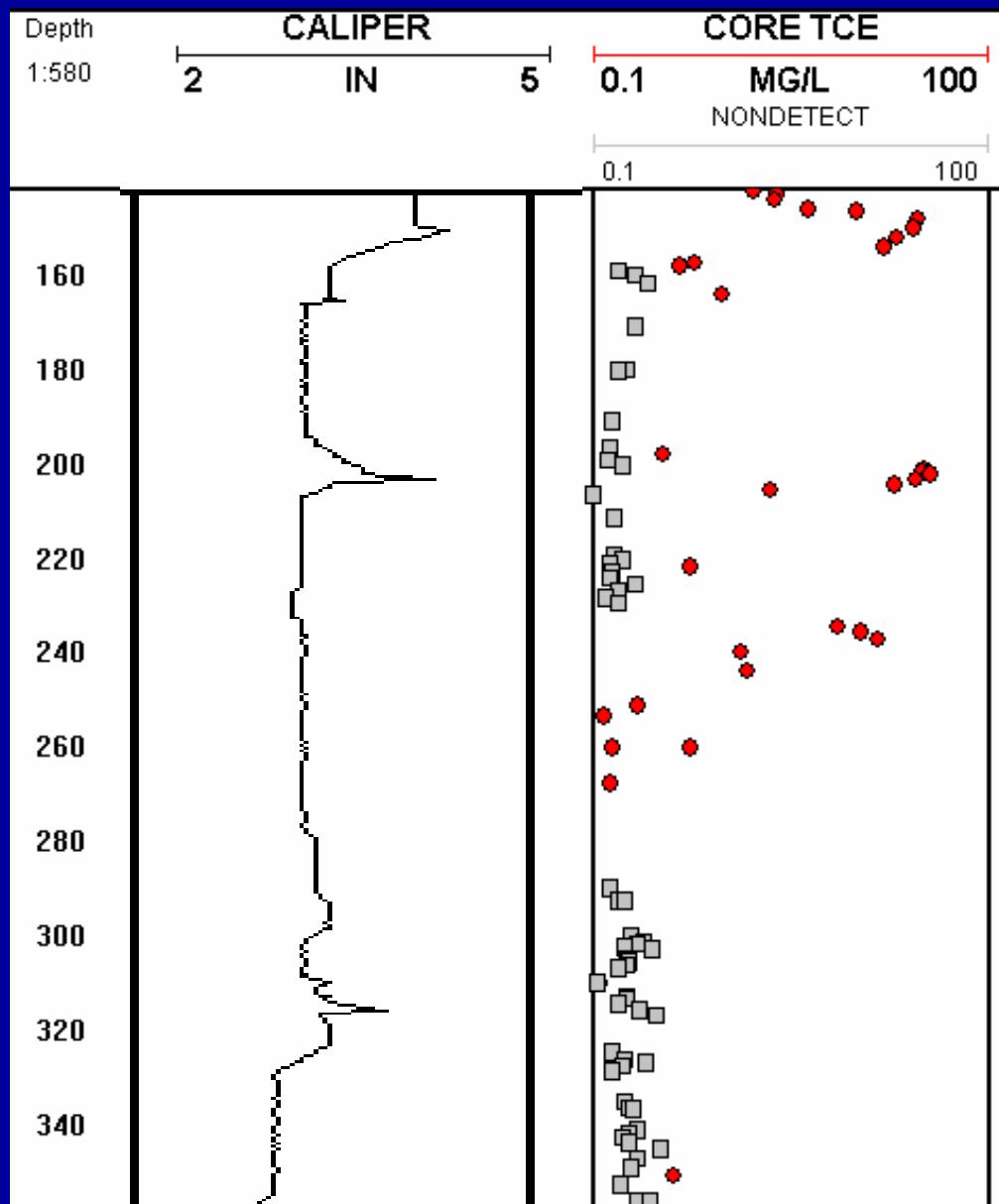
# **GROUND-WATER SAMPLES FROM DISCRETE-ZONE MONITORING SYSTEM**



**High TCE at 201-foot zone**

**High TCE at 312-foot zone**

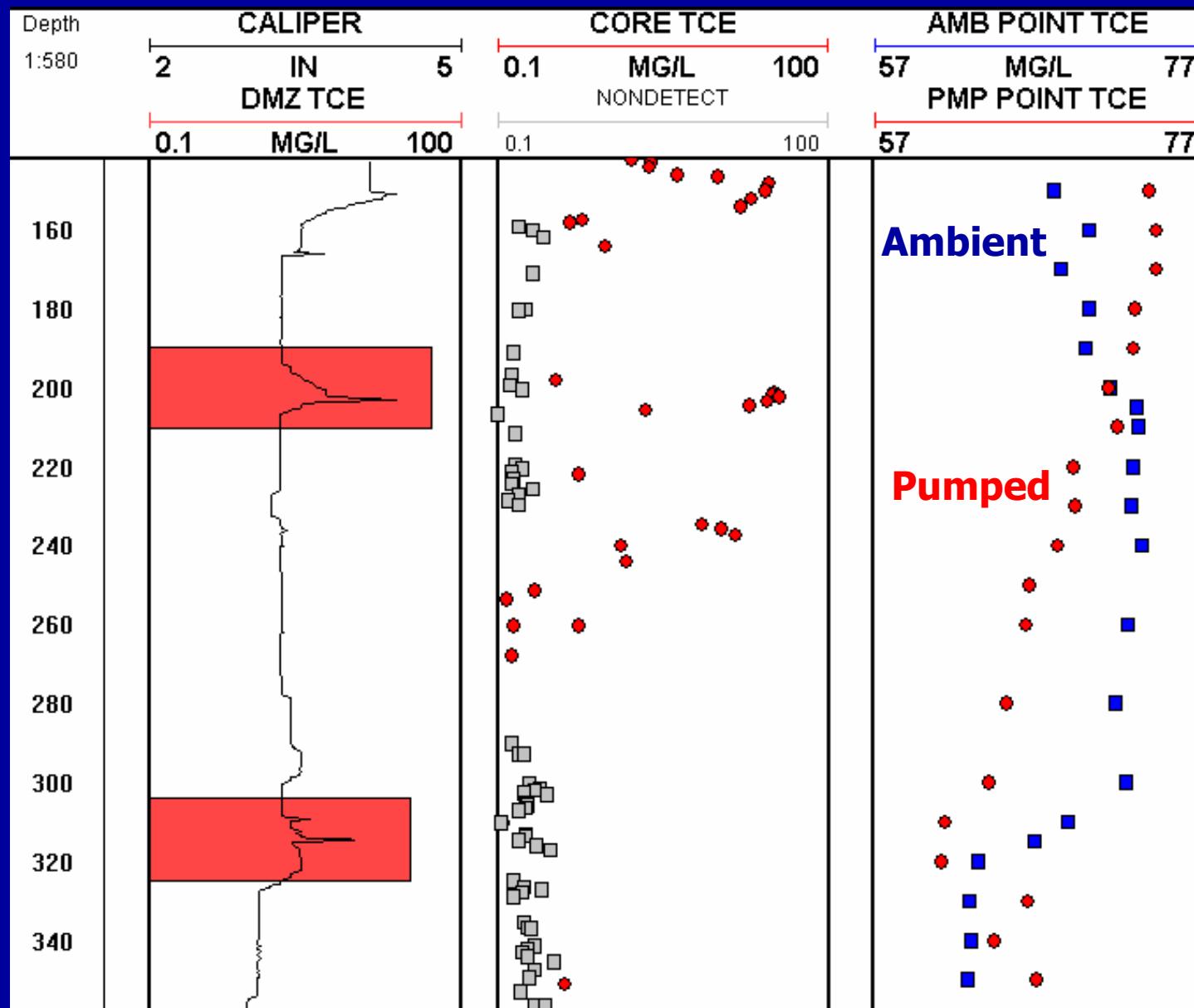
# CORE ANALYSIS MATRIX DIFFUSION



**High TCE in the matrix  
near the 201-foot zone**

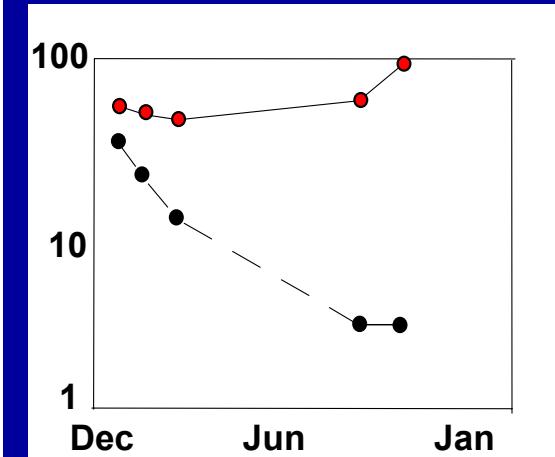
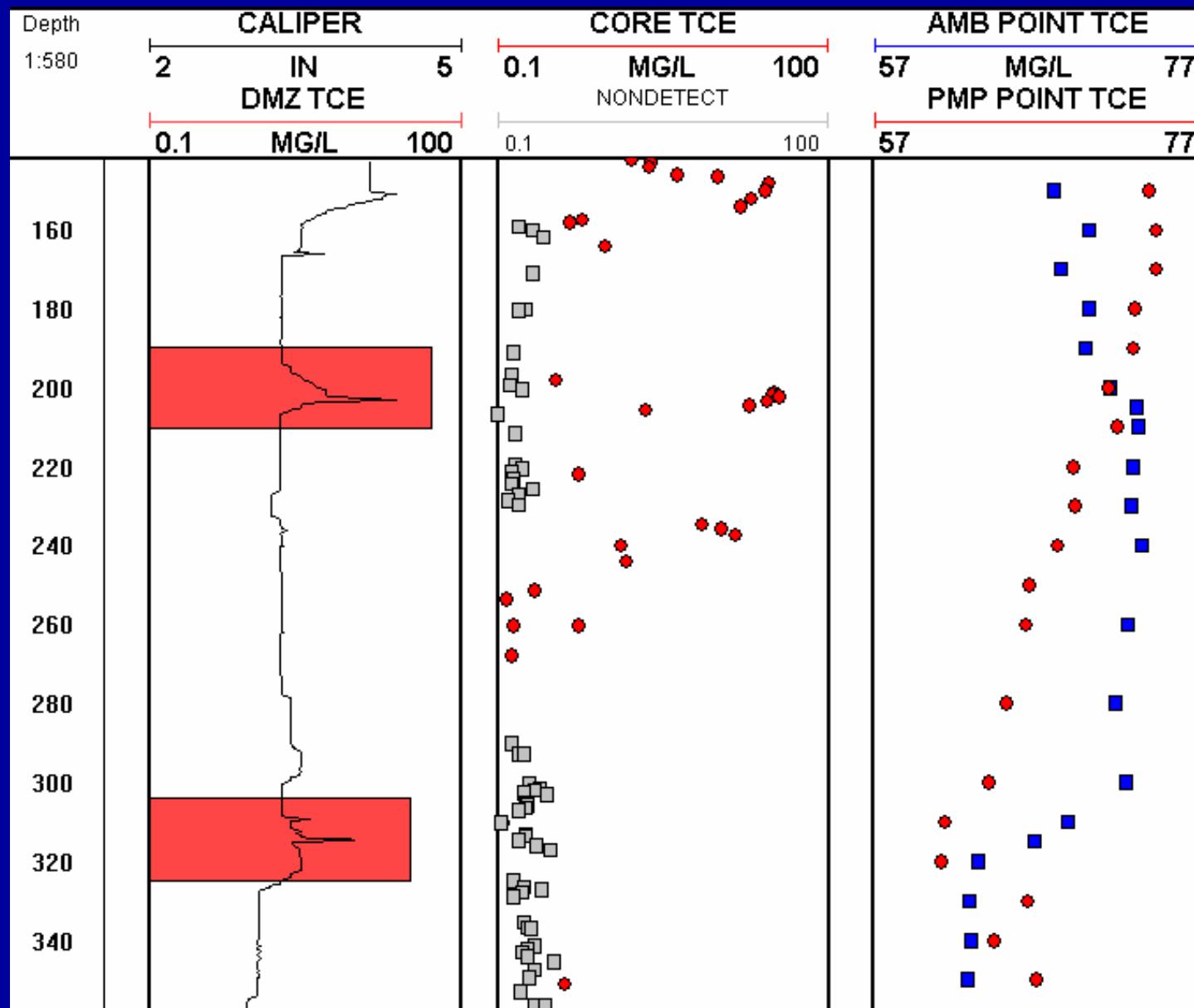
**No TCE in the matrix  
near the 312-foot zone**

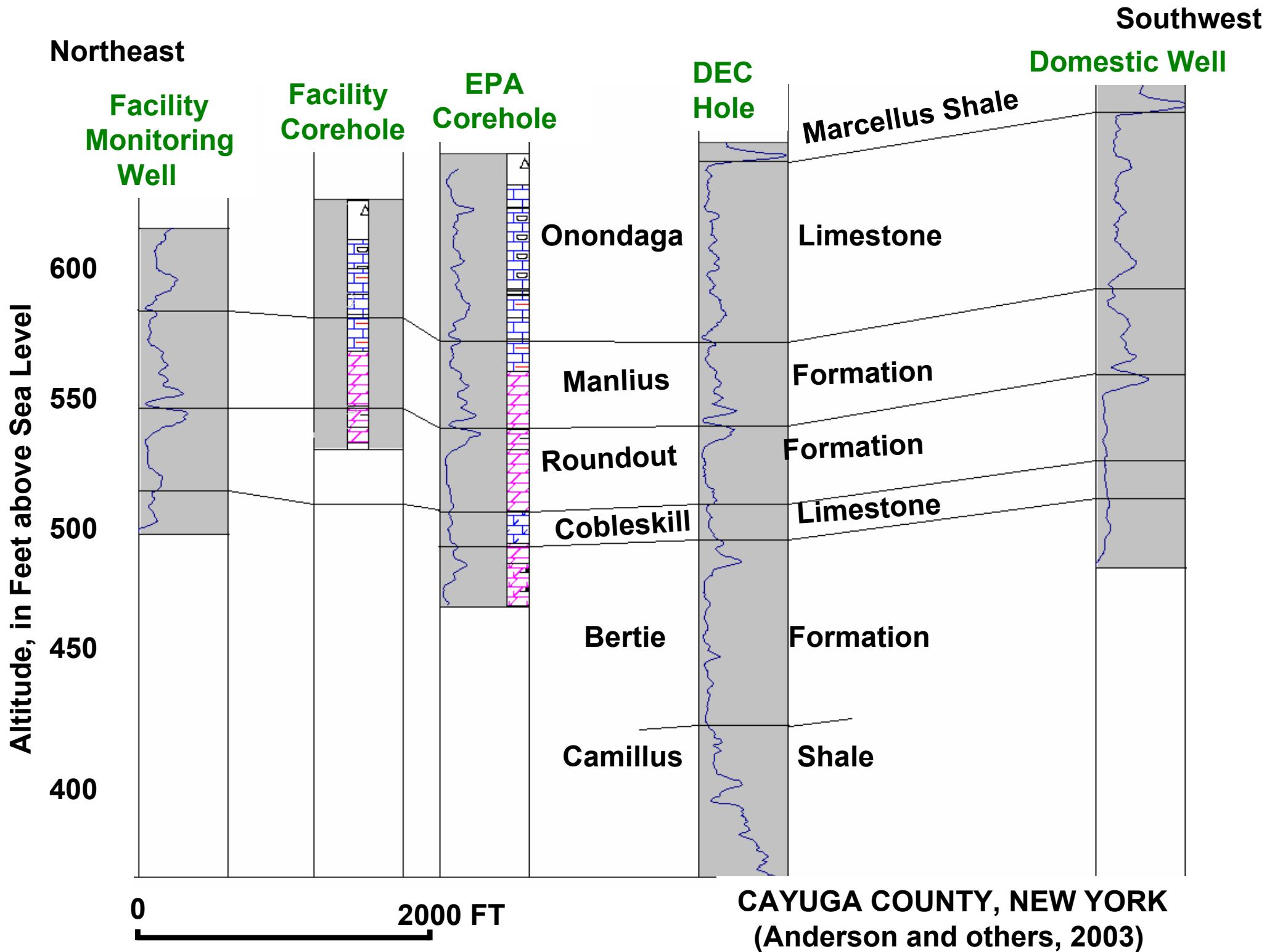
# CROSS CONTAMINATION

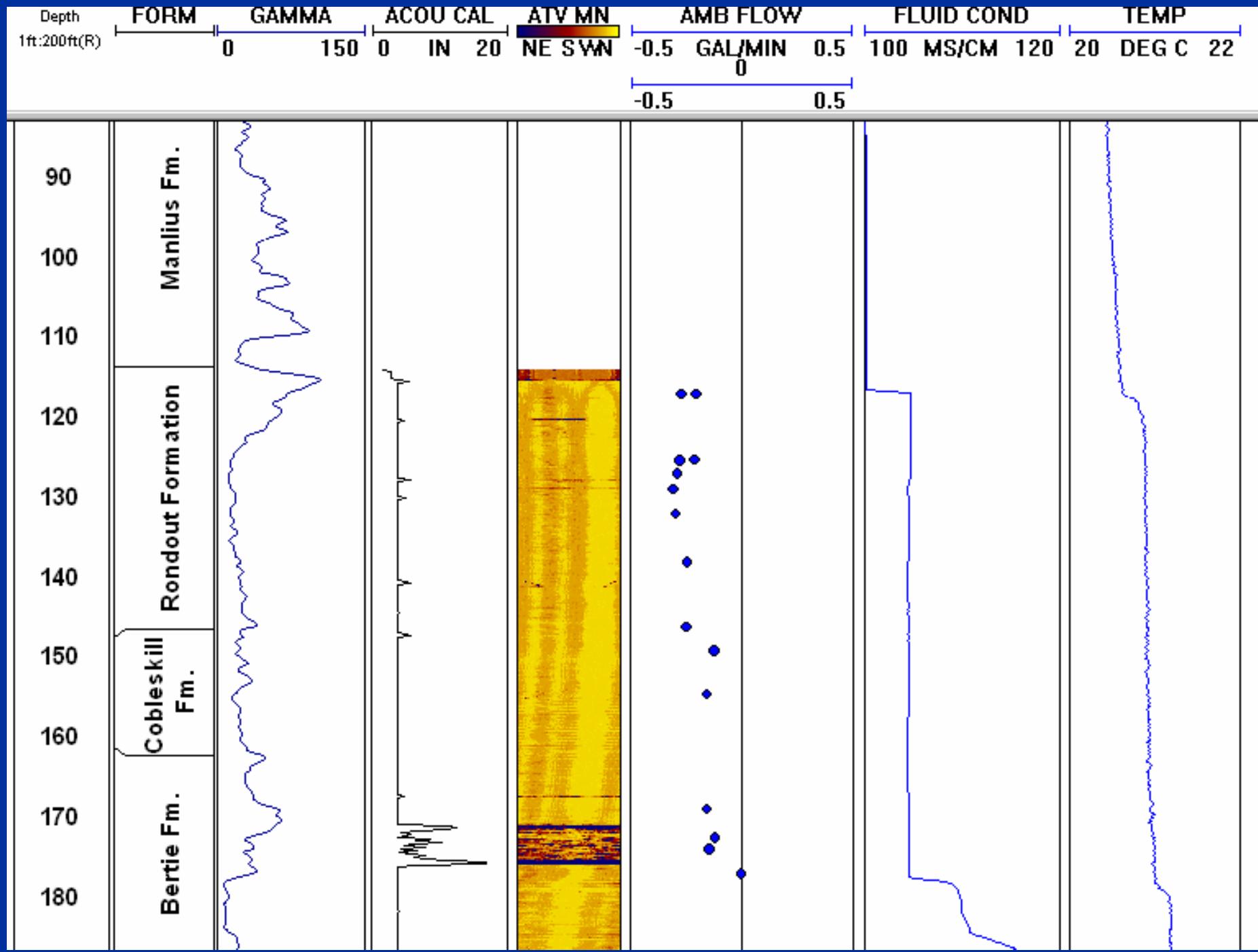


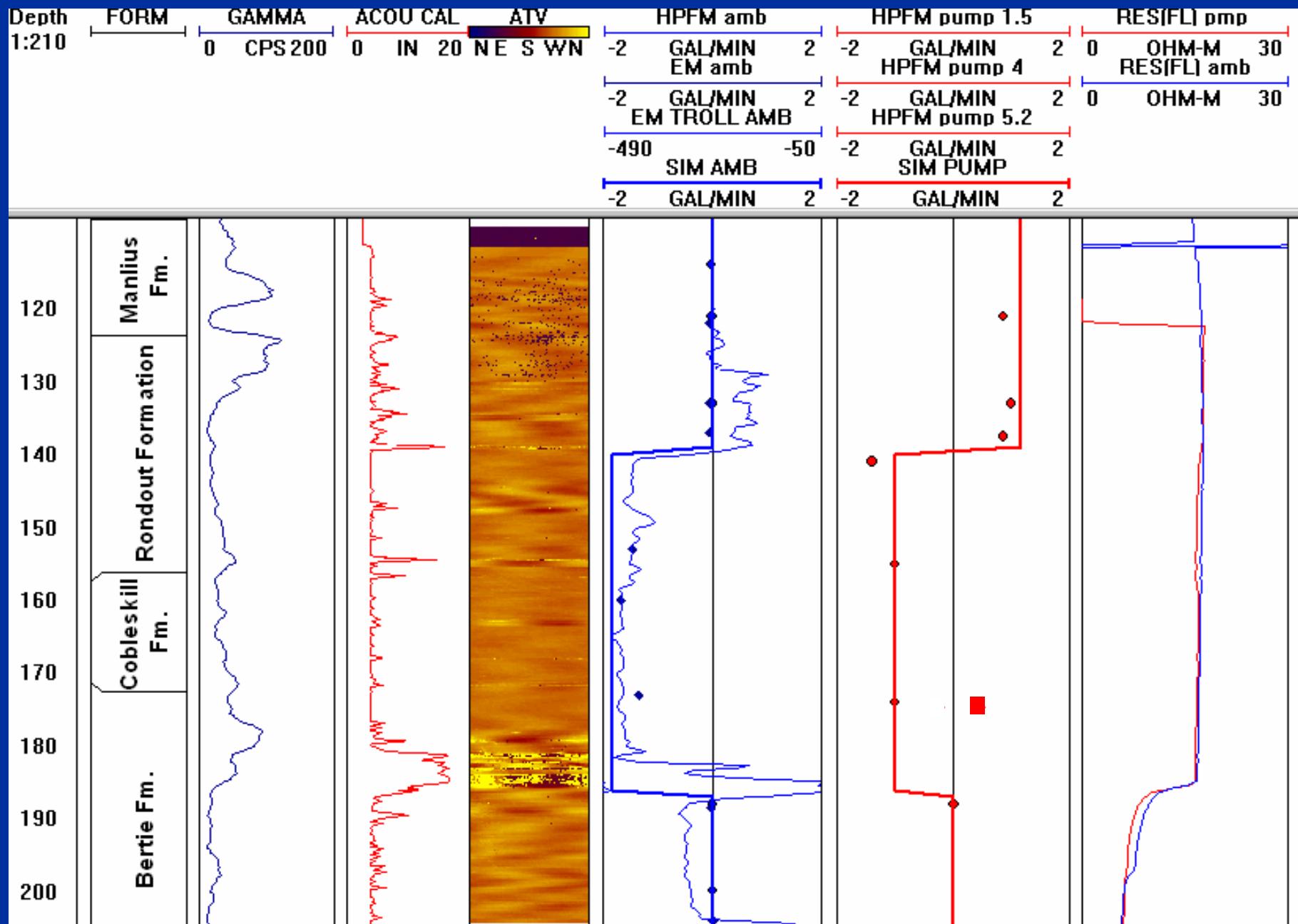
TCE point samples

# CROSS CONTAMINATION

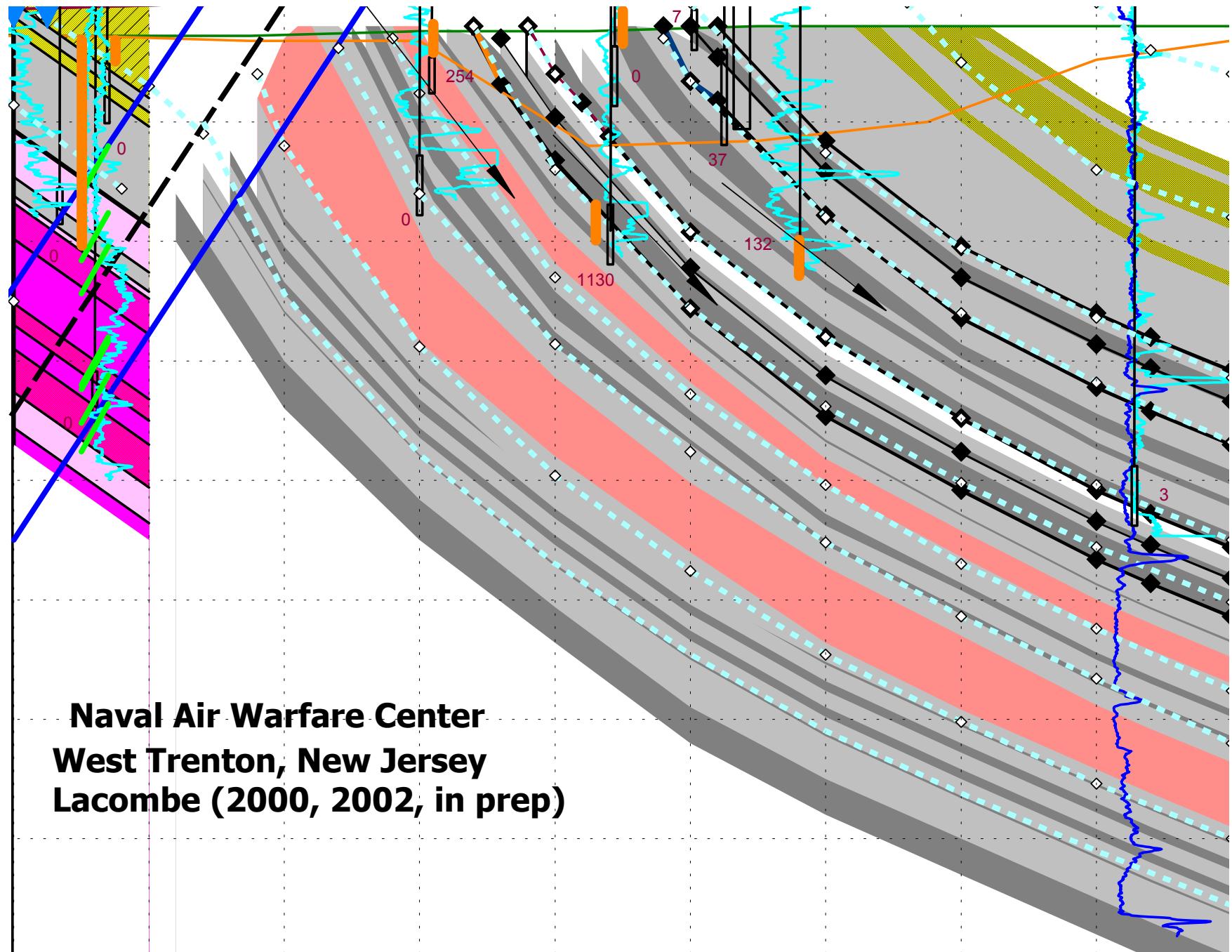




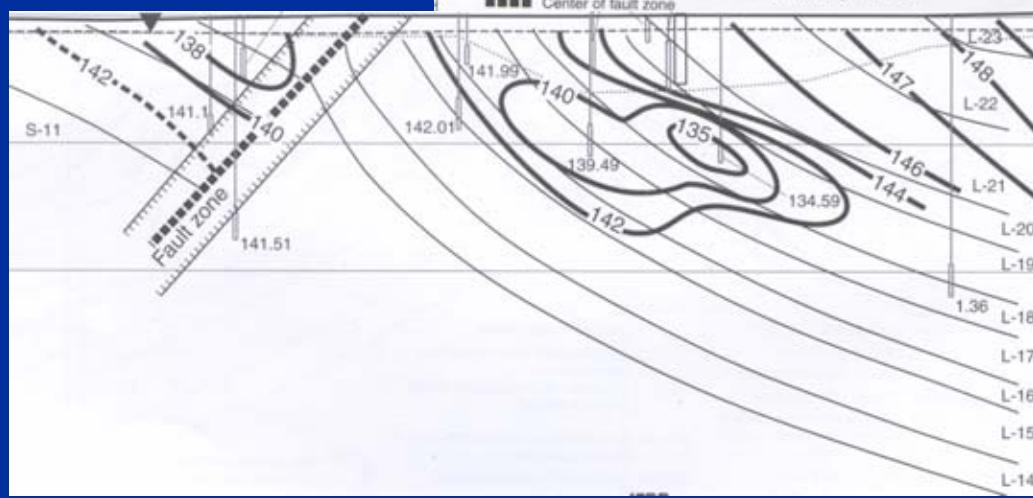
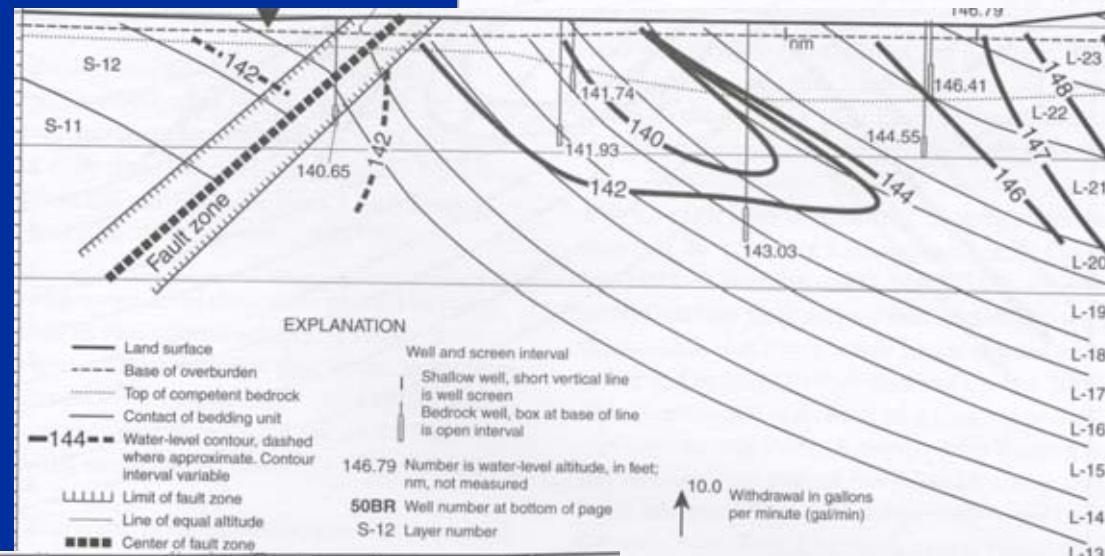
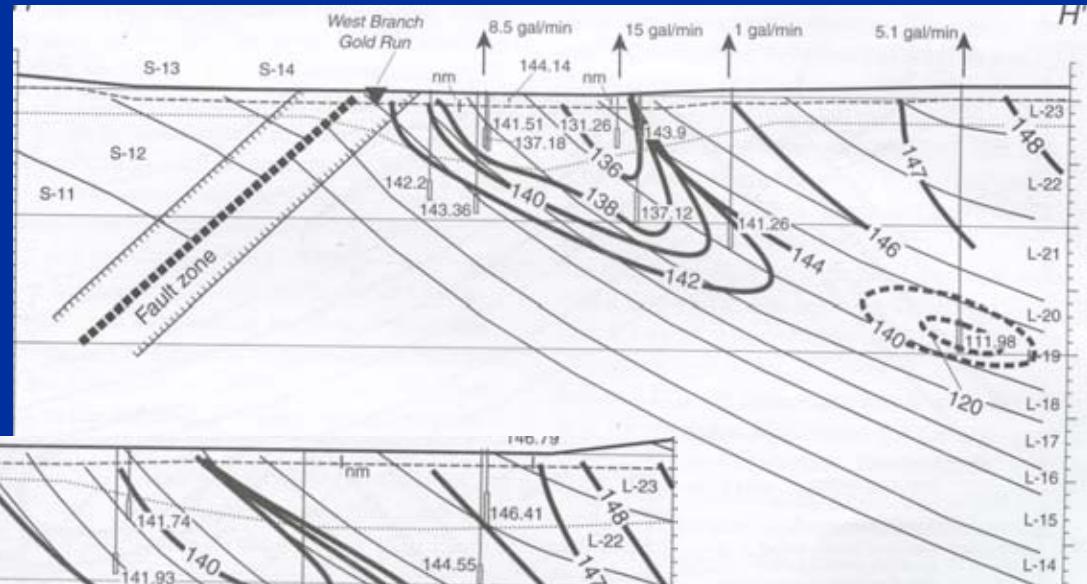




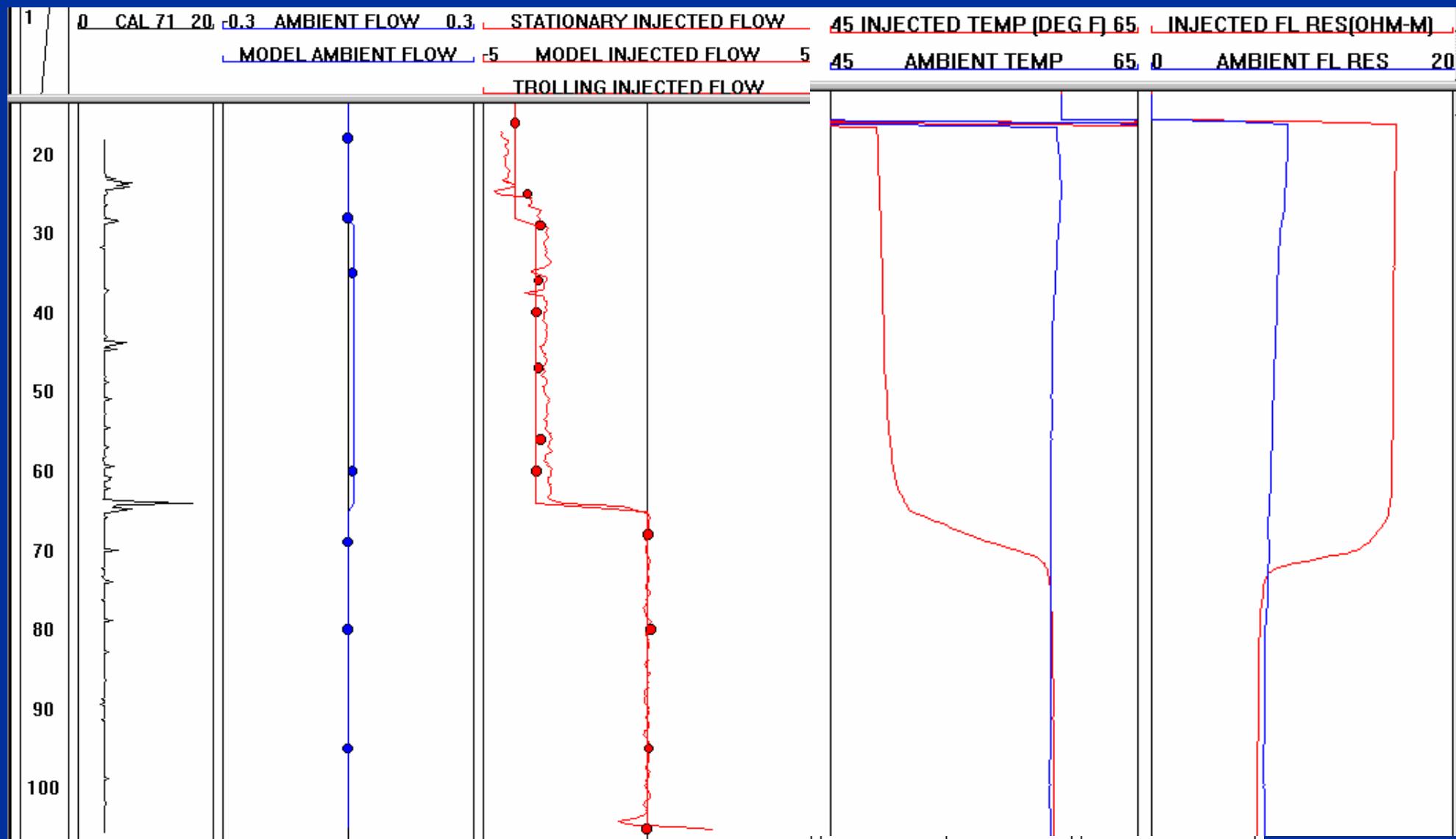
# GAMMA AND CORE LOGS FOR GEOLOGIC FRAMEWORK



# Propagation of Stress

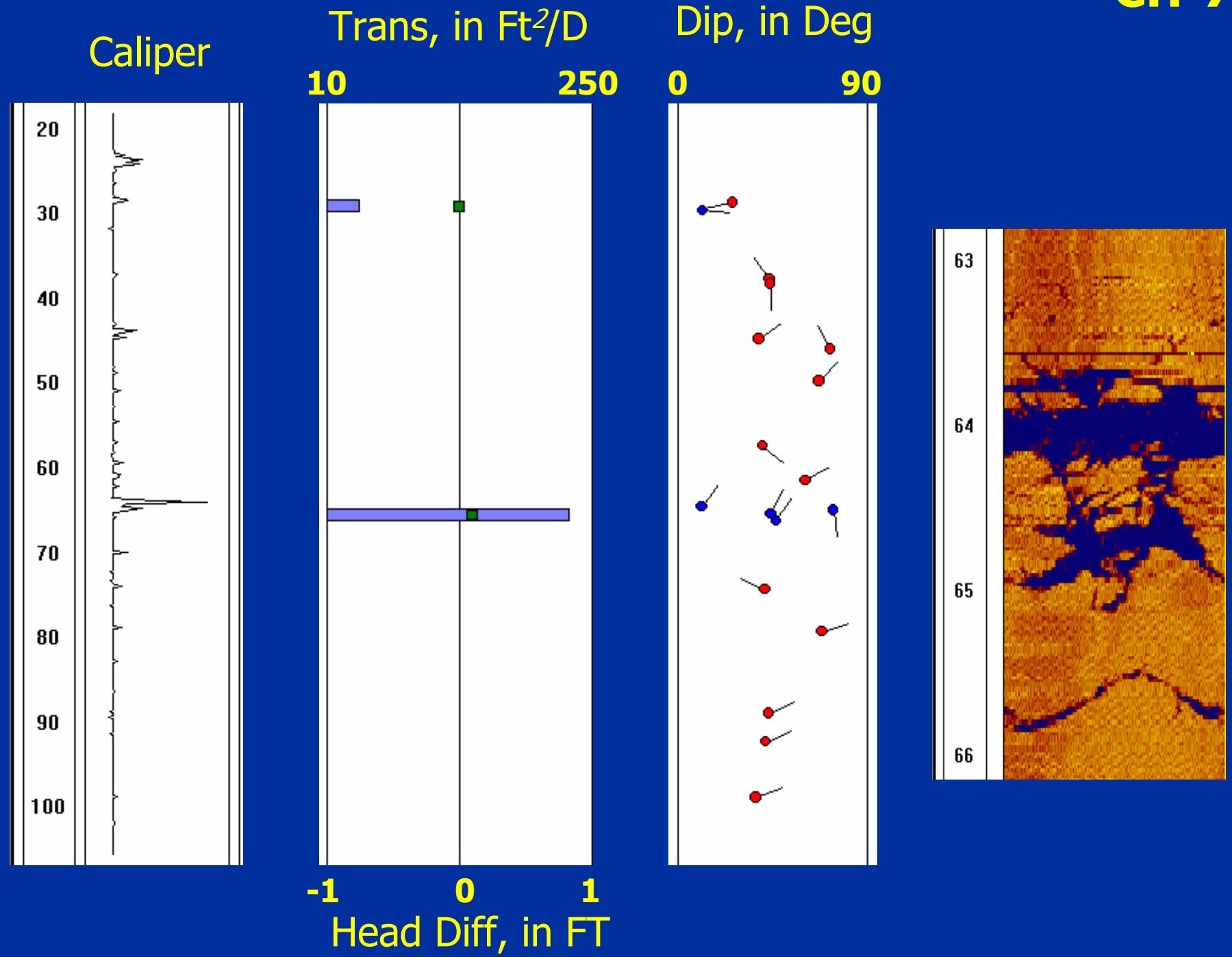


# from Pump-and-Treat



FLOW ZONE CHARACTERIZATION BY FLUID AND FLOWMETER LOGGING

**CH-71**

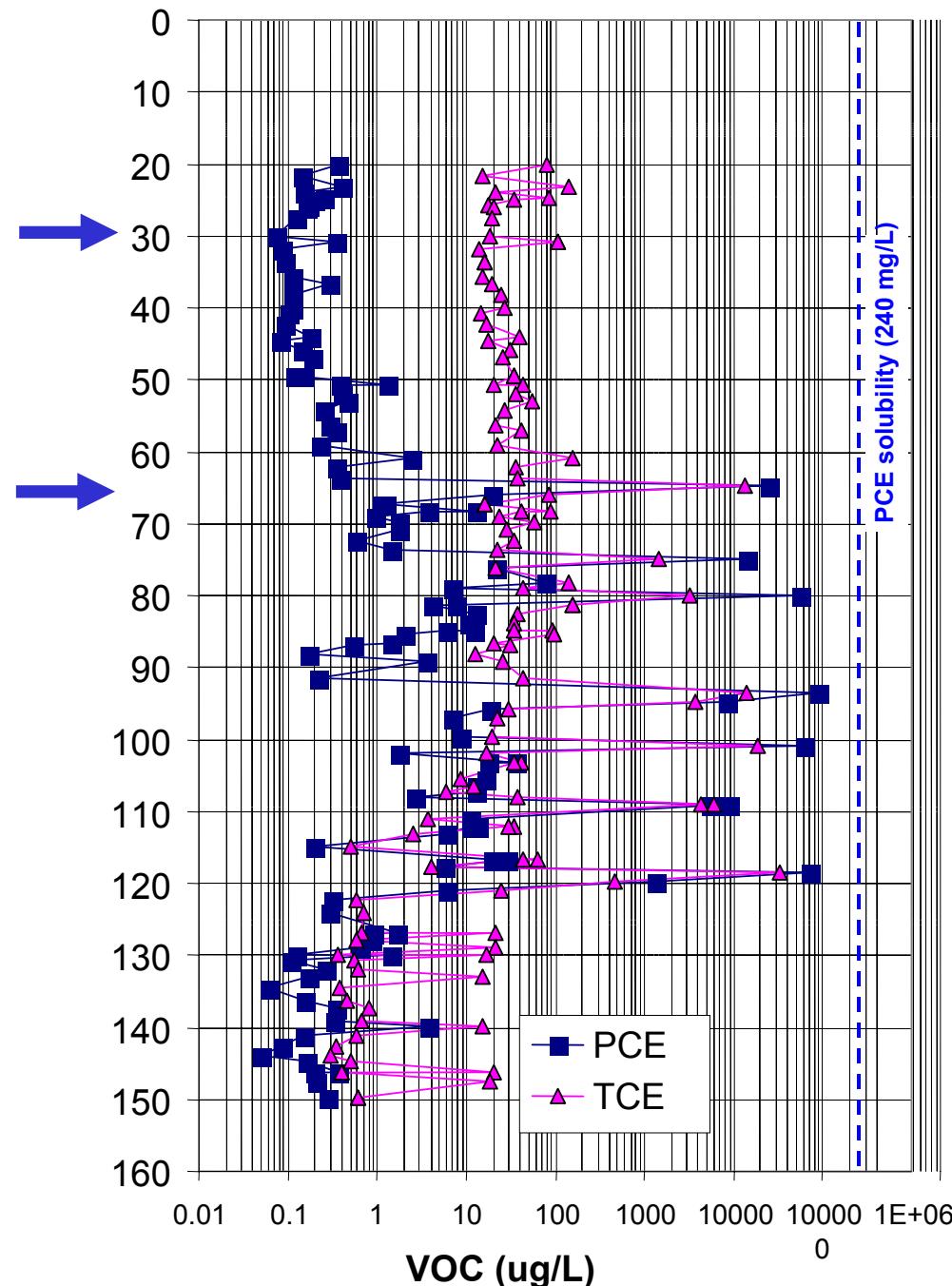


# Core Analysis

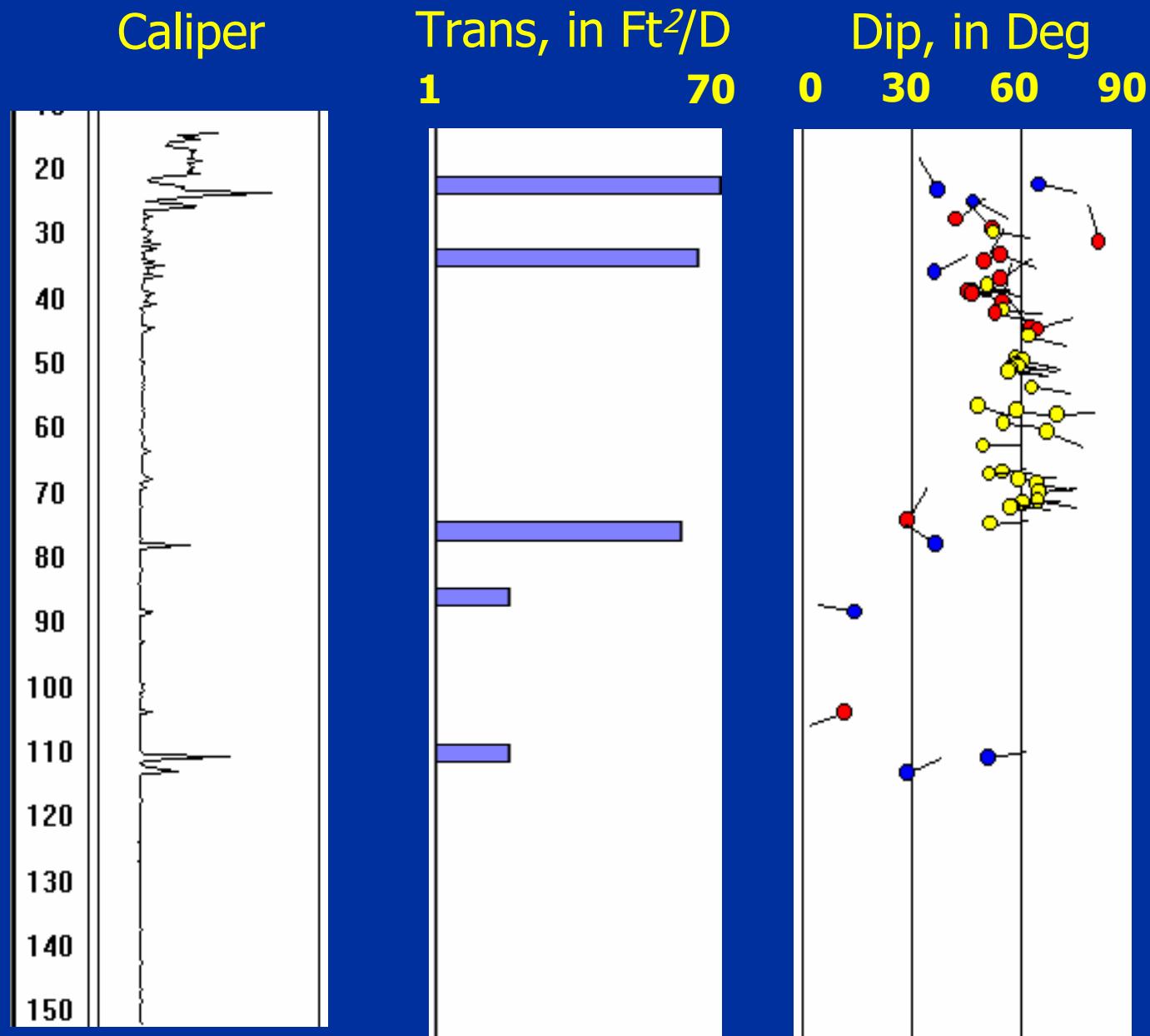
DZM

**CH-74  
(near CH-71)**

Flow Zones

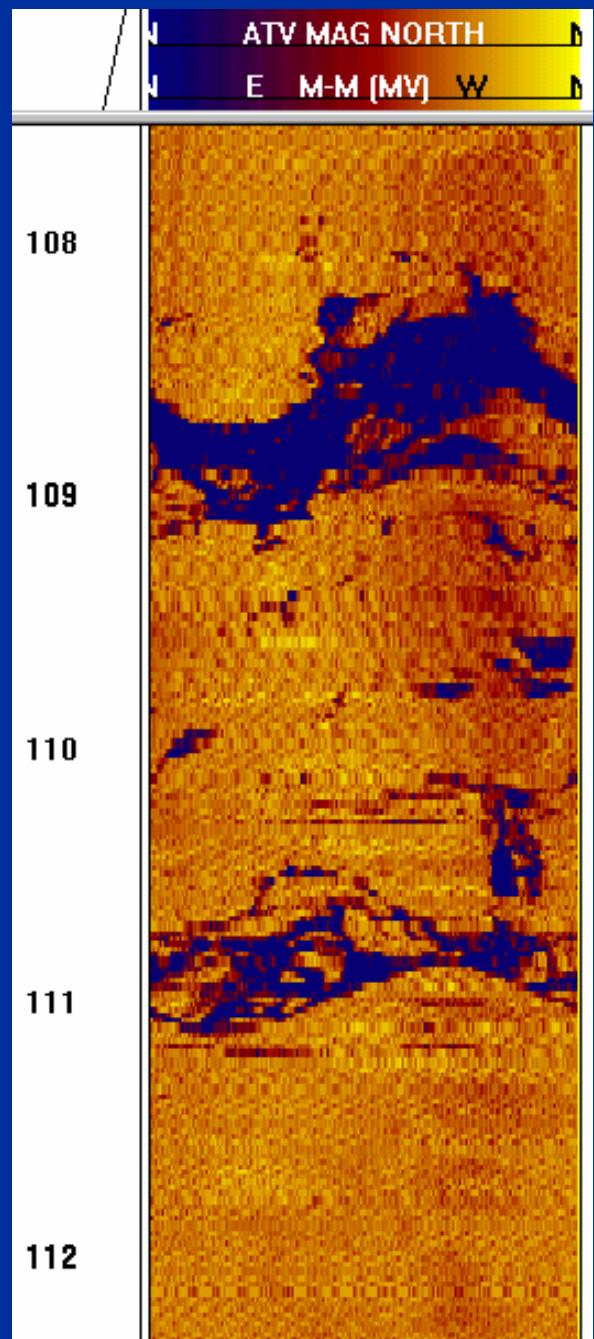
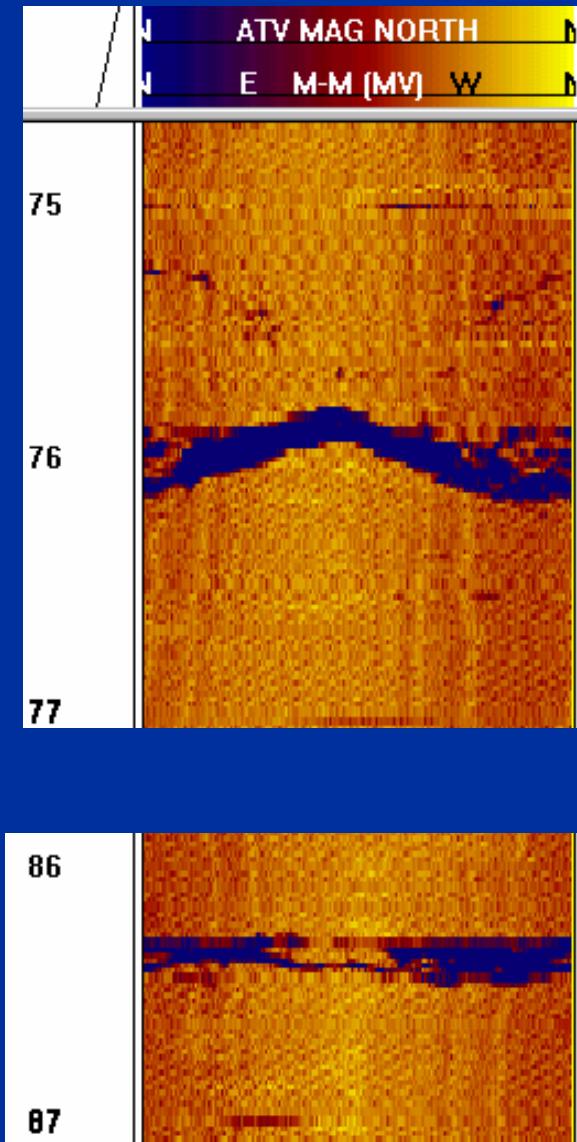
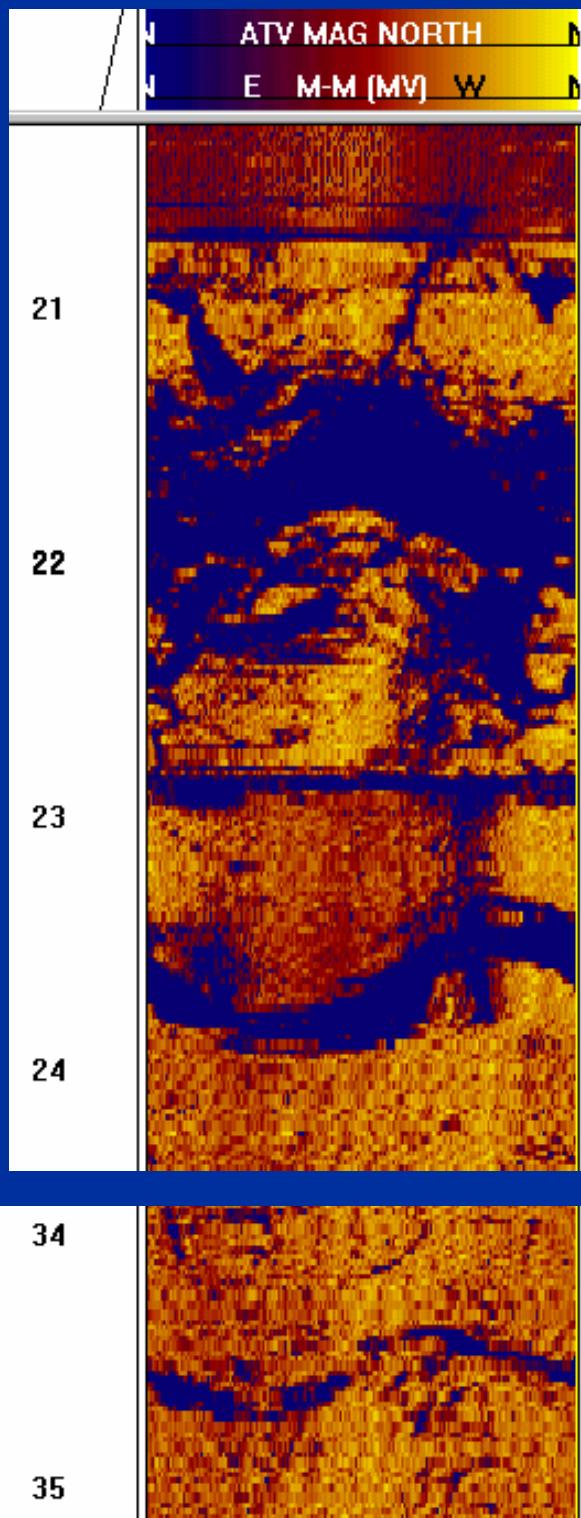


DZM PORTS	Aqueous Concentrations
1	PCE – 8 ug/L TCE – 5 ug/L c-DCE – 350 ug/L
2	PCE – 4 ug/L TCE – ND c-DCE – 1088 ug/L
3	PCE – 458 ug/L TCE – 123 ug/L c-DCE – 2802 ug/L
4	PCE – 9183 ug/L TCE – 382 ug/L c-DCE – 524 ug/L
5	PCE – 13,988 ug/L TCE – 3,699 ug/L c-DCE – 15,155 ug/L
6	PCE – 172 ug/L TCE – 259 ug/L c-DCE – 11,745 ug/L



**CH-65**

# FLOW ZONES CH-65

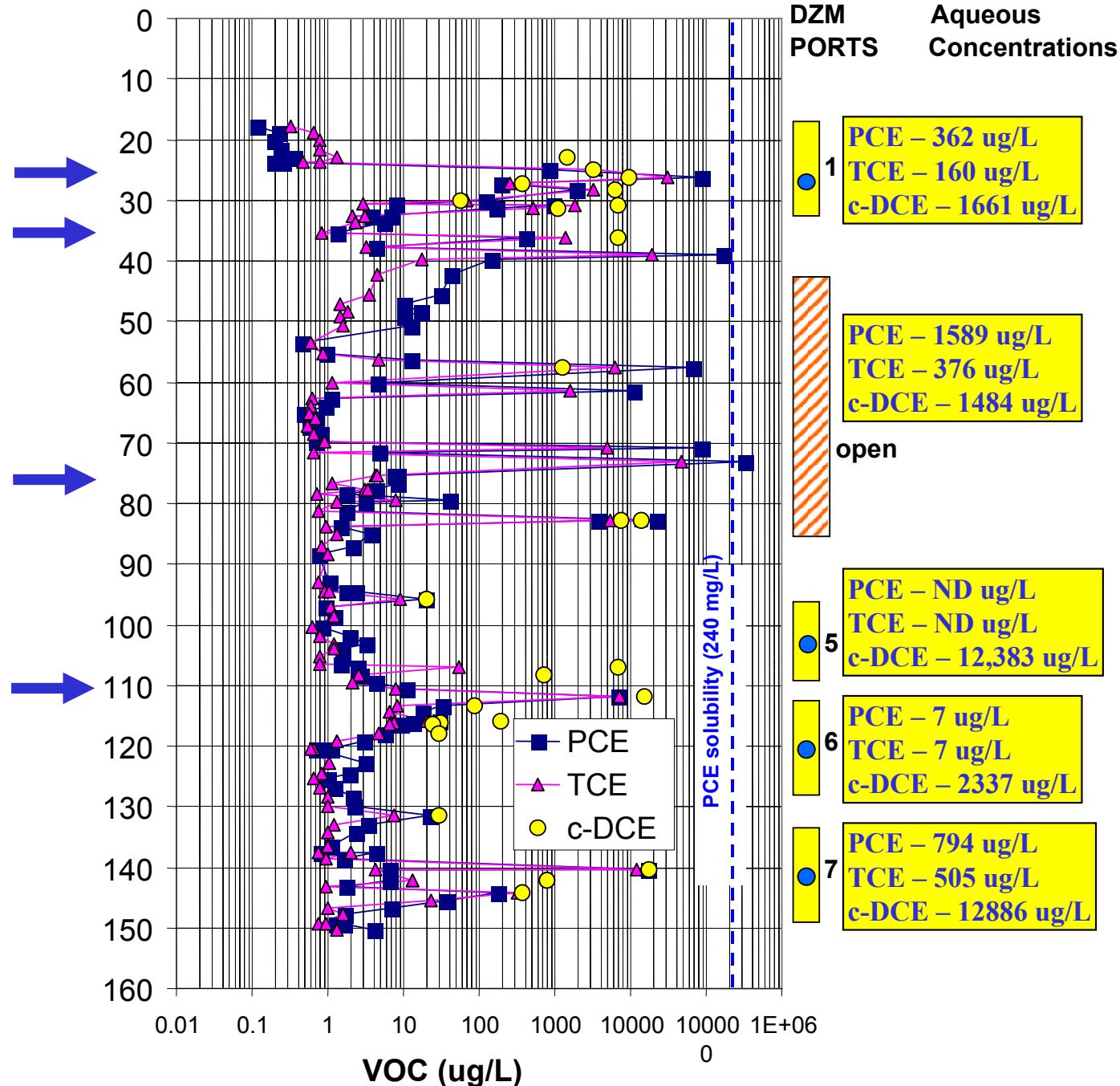


# Core Analysis

DZM

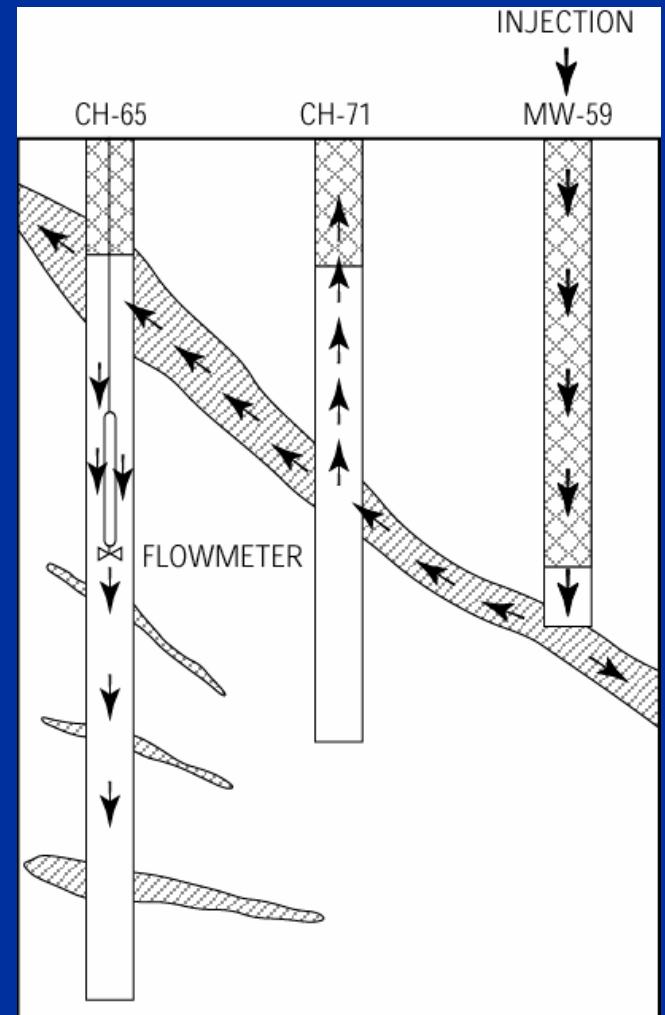
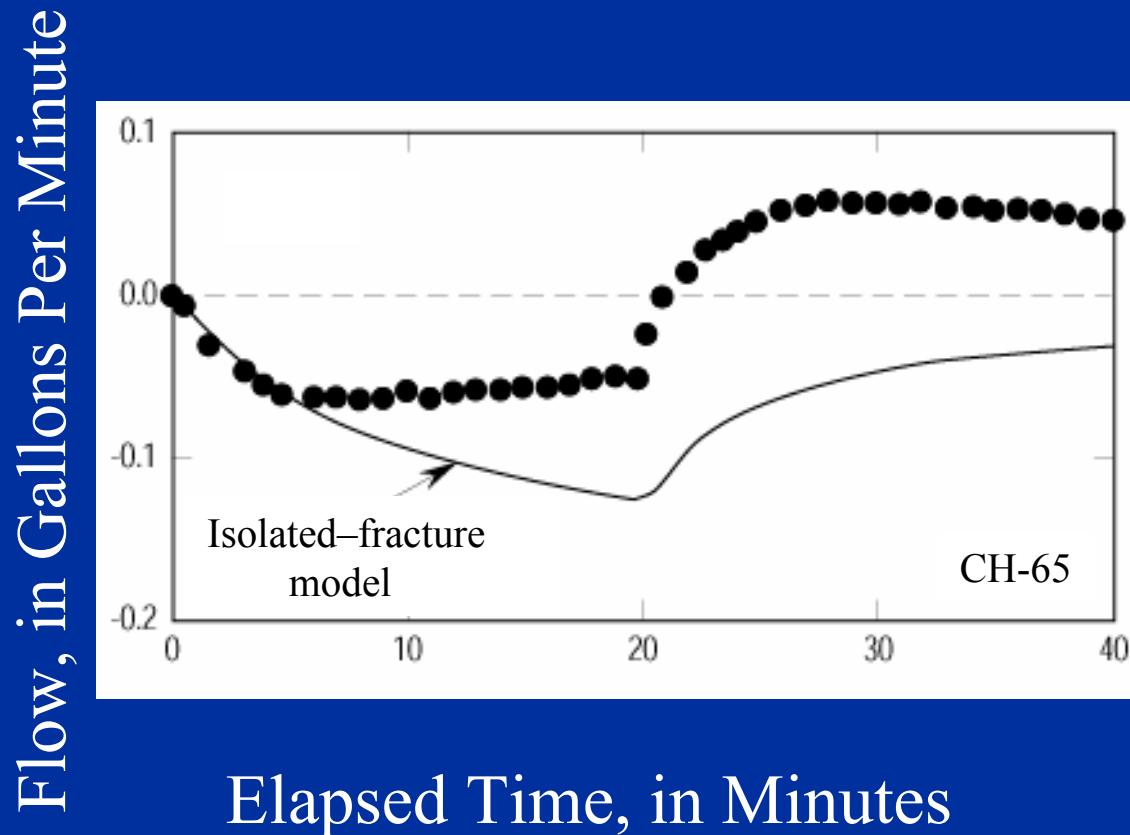
**CH-75  
(near CH-65)**

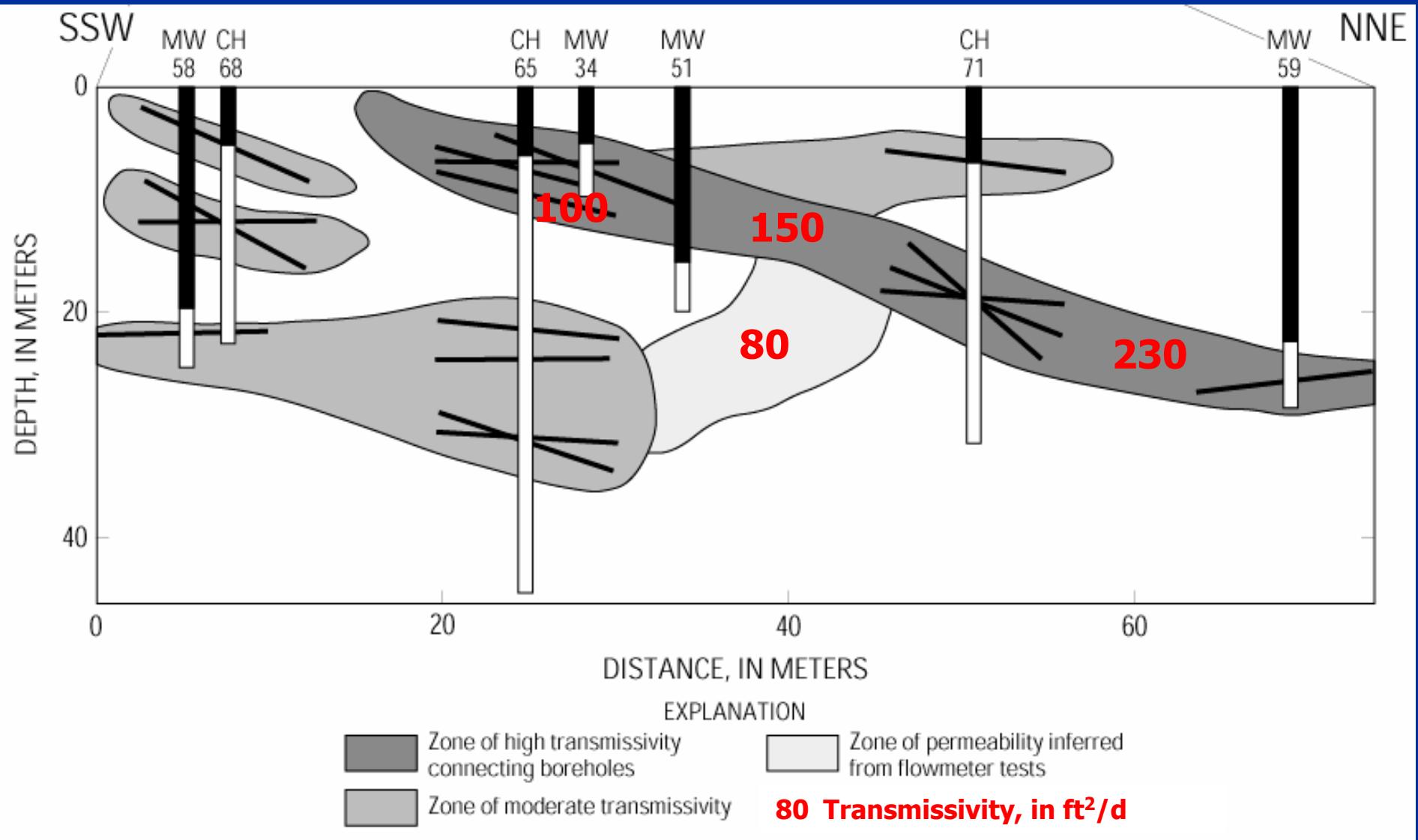
Flow Zones



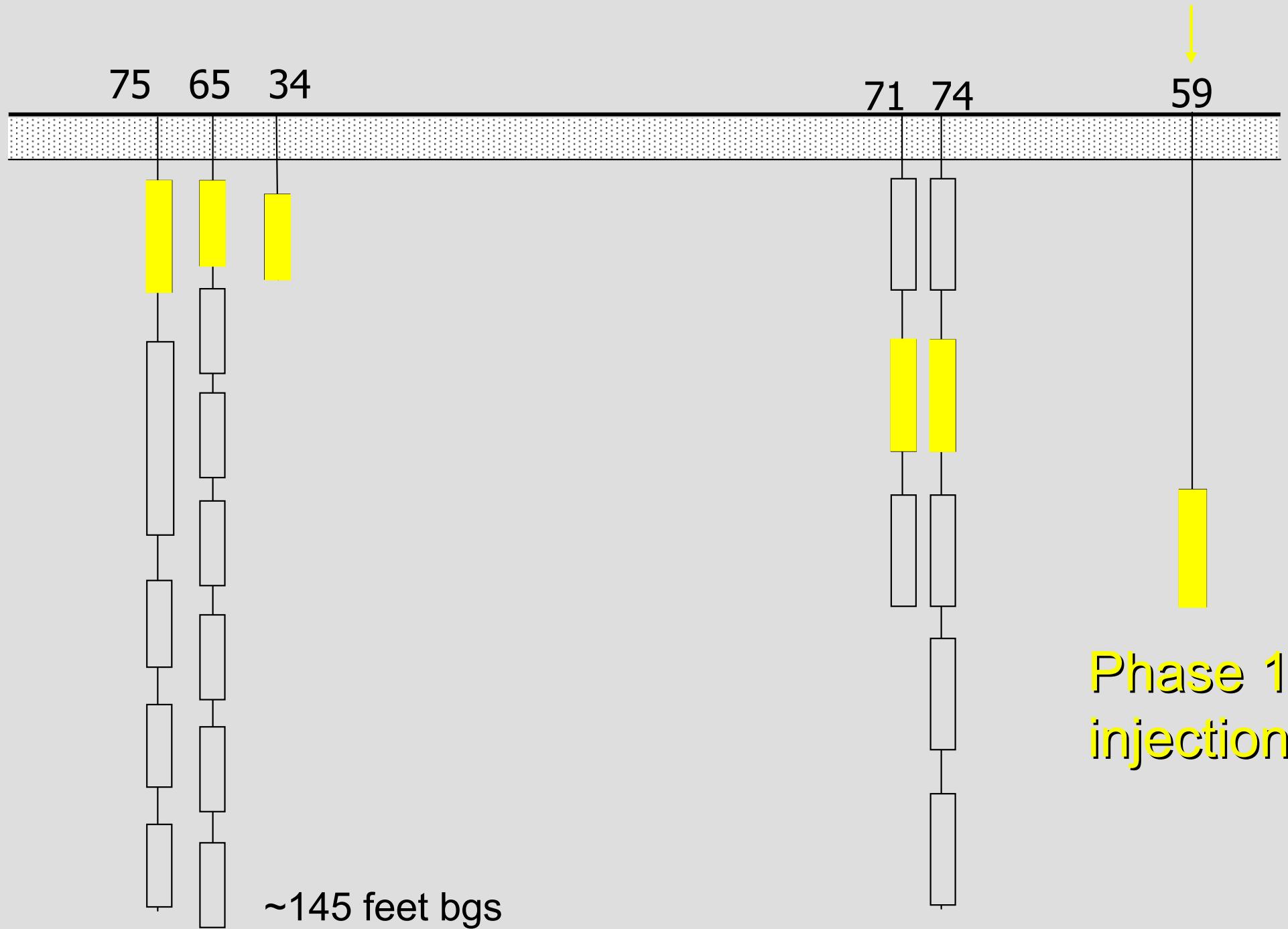
# CROSSHOLE FLOWMETER TEST

## Watervliet Arsenal, New York





# Potassium Permanganate Injection



# SUMMARY AND CONCLUSIONS

- Borehole geophysics proven to be an effective investigative method at fractured-bedrock VOC sites
- Most useful when integrated with core, hydraulic test, and monitoring analysis
- Stratigraphic framework; fracture, fabric, and bedding distribution and orientation; and delineation of major flow zones and estimation of their transmissivity and head
- Critical information for design/evaluation of discrete-zone testing and monitoring systems, effects of open holes on water-quality sampling programs, and remedial measures